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SIGNAL NOISE/INTERFERER COMBINER UNIT PROGRAMMABLE (SINCUP)

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ABSTRACT

The Signal Noise Interferer Combiner Unit Programmable (SINCUP) has been developed to facilitate laboratory performance testing of Very Low Frequency (VLF)/Low Frequency (LF) receivers. To accomplish this, the unit allows the combining in controlled amounts of various real-world environmental and manmade interference with an information carrying signal. The externally modulated signal is combined with internally/externally generated Gaussian noise and/or with an internally/externally generated interferer. In order to test modern digital processing techniques, such as Adaptive Null Steering, Eigenvector Sorting, and Widrow-Hoff adaptive filters, SINCUP is capable of generating and meeting much higher signal-to-noise plus interference ratios than earlier channel simulators. The present software has been written to accommodate a dynamic signal-to-noise ratio (SNR) range from -60 to +60 db. Higher dynamic range units could be implemented.

BACKGROUND

SINCUP has been designed to test both analog and digital VLF/LF receivers. Long-range military communication channels are prone to noise perturbations, which can cause errors in received messages. The error rates are a function of signal-to-noise plus interference ratio and therefore extensive laboratory simulations are usually necessary to establish receiver performance as a function of this ratio. SINCUP provides a flexible test tool designed to support testing of VLF/LF receivers operating in the frequency range from 10 to 60 kHz and could be extended to 160 kHz with minor hardware modifications.

SINCUP was developed to replace earlier channel simulators which cannot function with today's advanced signal processing techniques that require testing formats of VLF/LF receivers at extremely low SNR's. SINCUP will also circumvent certain functionality problems that had become manifest, such as ground loop problems which arose while testing signal levels in the microvolt range. These problems are caused by the physical separation of various parts of the system under test using different ground points in a laboratory area where several other systems are under test.

A typical test configuration involves a signal source (usually transmitting a test message), noise and interferer sources, a true-root-mean-square (TRMS) meter to measure signal-to-noise interferer levels, the receiver under noise stress, and other monitoring equipment (such as bit or character error counters). A typical test setup using SINCUP is shown in figure 1. It consists of a communication signal source, a channel simulator, and the receiver under test. SINCUP is the central hardware component used to simulate the channel. The internally provided SINCUP capabilities that generate interference and Gaussian noise can be supplemented or supplanted through use of an external interferer source and/or an external Gaussian noise generator. The programmable features of SINCUP automate testing and provide repeatability of test results.

The communication signal source consists of a message source, such as a tape loop on a transmit distributor, connected to the input of a transmit modem. A message is then processed in one of several ways by the transmit modem; for example, 1' could be encoded to provide error detection and correction, encrypted, or multiplexed with other inputs. The resulting binary sequence is then converted to an analog signal through one of several modulation techniques, such as Frequency Shift Keying (FSK) or Minimum Shift Keying (MSK). The modulated signal is then amplified and broadcast.

The broadcast signal is normally propagated through the atmosphere and received along with other VLF/LF signals (manmade interferers) by the receiver. In the case of a laboratory measurement, the channel can be simulated by attenuating the communication signal to account for propagation losses of the signal and by a linear combining network to add to the communication signal both interference and environmental noise. In the operational environment, interference and noise levels range widely relative to the communication signal levels. Thus, in order to characterize receiver performance, simulations must reproduce a wide variety of conditions. Multiple channel effects, such as sea state effects, must be imposed by other techniques not represented in figure 1.

In order to characterize the channel as simulated through the addition of interference and noise, each of the noise and signal sources are monitored prior to the receive modem in a known and calibrated bandwidth to determine signal-to-noise and signal-to-interference levels. SINCUP allows the user to select signal, interference, and noise levels and exercise the receiver at these levels for selected periods of time. If a preformatted test message is used, it is easy to count the character errors that have occurred for the given signal-to-interference plus noise level, and thus obtain a point on the receiver operating curve (character error rate (CER) vs. SNR curve). After the completion of a series of tests at different signal-to-interference plus noise levels, it is easy to construct a waterfall, or CER vs. SNR performance curve for the receiver.
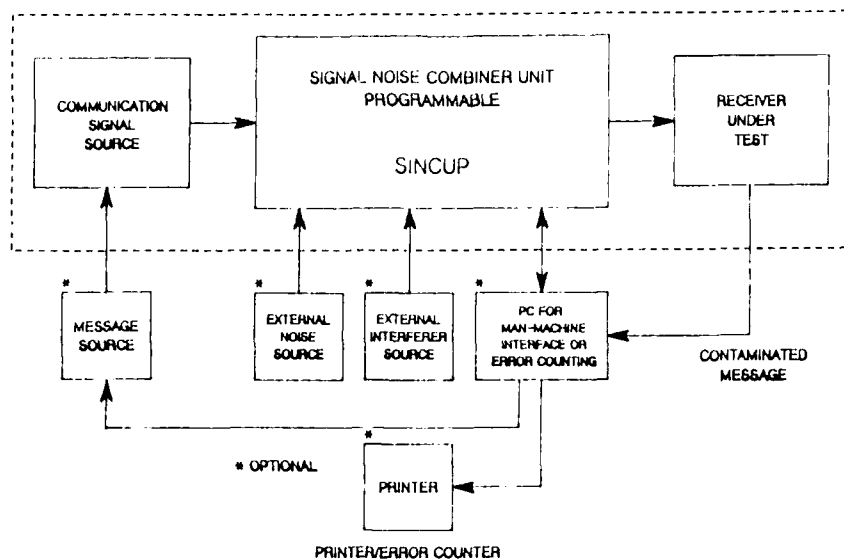
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TYPICAL CHANNEL SIMULATOR

Figure 1. Receiver Test Setup with SINCUP

DESCRIPTION

SINCUP is an automated standalone test support tool conceived, designed, built and tested at NAVOCEANSYSCEN. SINCUP converts time-varying voltage values of analog signal and noise components to TRMS values so that appropriate measurable components can be attained for SNR computations. The TRMS values are digitized and processed in fixed-point binary format so that they are represented accurately.

A functional block diagram of SINCUP is shown in figure 2. Subsequent paragraphs describe the various SINCUP components.

The SINCUP's circuitry and related hardware mount in a 17" x 12" x 20" rack-mountable chassis. In order to minimize alternating current induced noise, a direct current (DC) powered fan is used for cooling. Also, contrary to the wide use of switching power supplies in today's state-of-the-art designs, it was decided to use linear power supplies due to their low noise characteristics (despite their considerably larger sizes). The multi-output linear power supply rack mountable is separately mounted beneath SINCUP's chassis to minimize self-noise.

SINCUP's controlling and processing power is provided over a STD Bus system. A front panel mounted Microterminal with an ASCII format keyboard and a 16-character light-emitting diode (LED) display provides the man-machine interface for SINCUP, while dual RS-232 I/O ports provide data and computer interfaces. The computer interface allows SINCUP to be controlled by an externally connected IBM-compatible PC XT/AT. The PC's processing and displaying power relieves SINCUP of generating system functions (which are not presently implemented) such as providing error counts, printouts, and most importantly, the ability to automate test scenarios with display presentations.

DIGITAL CONTROL

See figures 2 and 3.

The SINCUP's control and processing power is generated by the built-in STD Bus system consisting of six (6) STD BUS boards. The central processing unit (CPU) board has 22 Kbytes of programmable read-only memory (EPROM) for program code and 2 Kbytes of random access memory (RAM) to store program variables and provide input/output (I/O) buffers.

The man-machine interface between the CPU and either the microterminal or the external PC is achieved by one Dual Channel RS-232 SYNC/ASYNC Communications board. Each of three Parallel Output Boards are capable of driving six buffered ports for command-word outputs to the Signal, Noise and Interferer Attenuators, to the Frequency
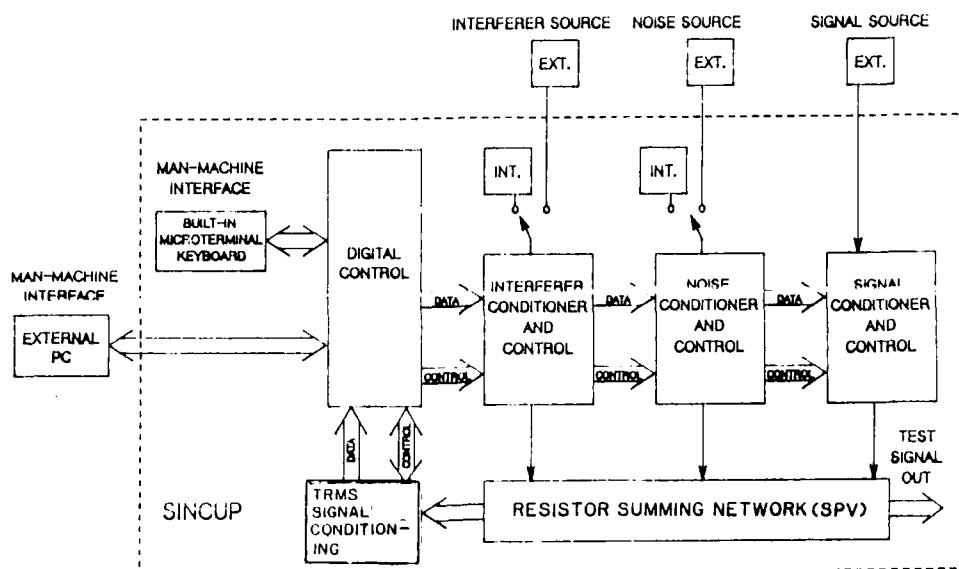
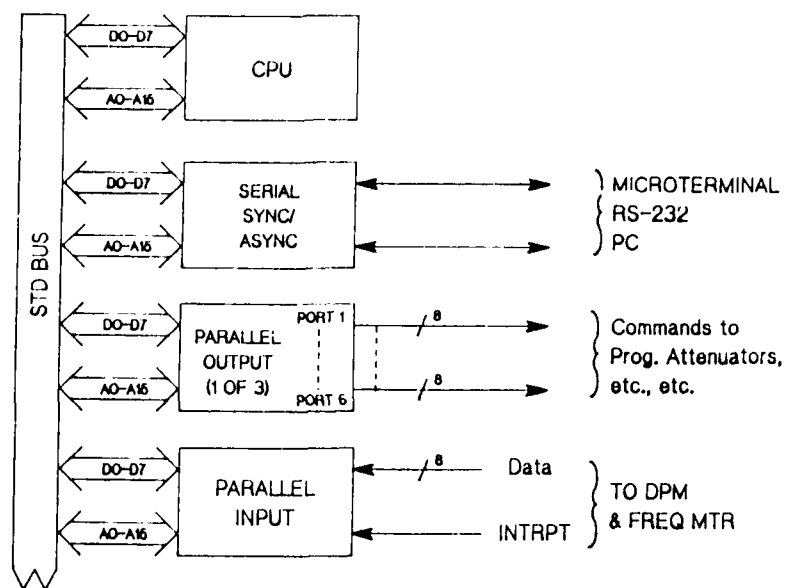Figure 2. SINCUP Functional Block Diagram

Figure 3. Digital Control

Synthesizer (interferer source), to the Dual Channel Programmable Buffer Amplifier (PBA) and to the various remotely located radio frequency (RF) relays.

The last STD BUS board provides six buffered parallel input ports used to recover the digitized data from the digital panel and the frequency meter.

SIGNAL CONDITIONING

See figures 4, 5, and 6.

SINCUP's remaining PC boards are non STD BUS type: there are three commercially acquired ones--"Gaussian Noise Source", "Frequency Synthesizer" (interferer source), and the "Sine Wave Converter" board, which converts the Frequency Synthesizer transistor-to-transistor logic (TTL) square wave output to a sine wave.

Additionally, there are three in-house designed PC boards:

(1) The "Programmable TRMS Signal Conditioner", which for the purpose of accuracy while converting to TRMS DC equivalent, preamplifies the selected signal or noise component prior to establishing a given SNR, converts this analog signal to a TRMS DC equivalent, and then attenuates this resultant DC signal to accommodate the DPM (digital panel meter/analog-to-digital converter) full scale range of 200 mv DC;

(2) the "Programmable Buffer Amplifier", which conditions the noise or interferer's sources in amplitude and line driving capabilities; and

(3) the "Isolation Systems Control" board, on which complete logic control and CPU interrupting capabilities are provided for the DPM and for the FREQUENCY METER (internal interferer's frequency display/interferer's analog-to-digital converter). Additionally, RF relay drivers, a 75 kHz low pass filter to produce band-limited Gaussian noise, and three isolation transformers are mounted on this board. The transformers ground isolate the external signal, noise, and interferer sources from SINCUP.

NOISE CHANNEL SIGNAL CONDITIONING FOR NOISE POWER
BANDWIDTH CALCULATION

It is important to mention that the 75 kHz Butterworth low pass filter was a logical design choice. SINCUP needed a precisely defined frequency of 75 kHz, along with a filter providing constant amplitude in the pass band and sharp roll-off at the 3 db points. Such filter characteristics would allow operator-aided determinations of Noise Power Bandwidth by empirical means. Then adequate calibration Gaussian noise "K" factors could be obtained for use during SNR computations (see Signal Handling Computations to follow). SINCUP should also be capable of upgrades which allow the
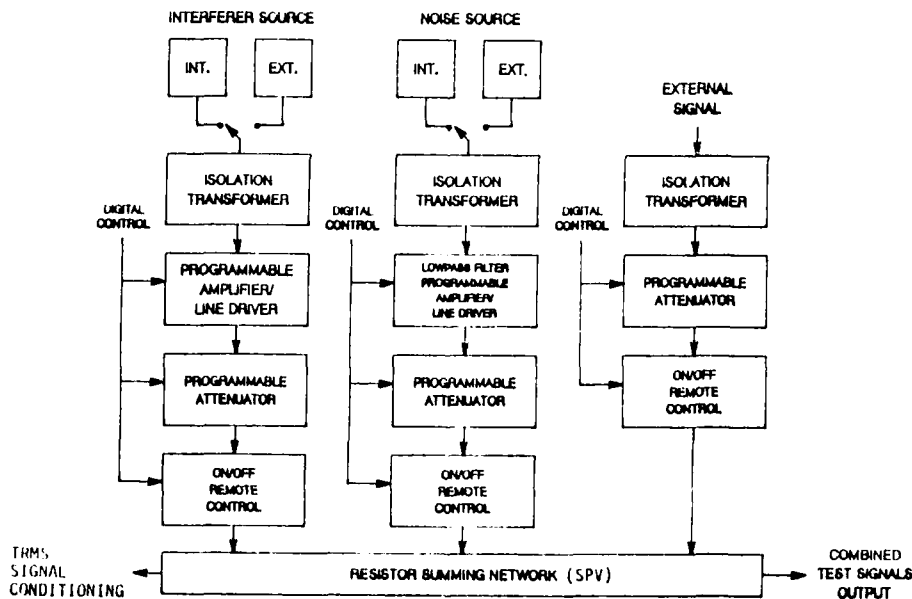

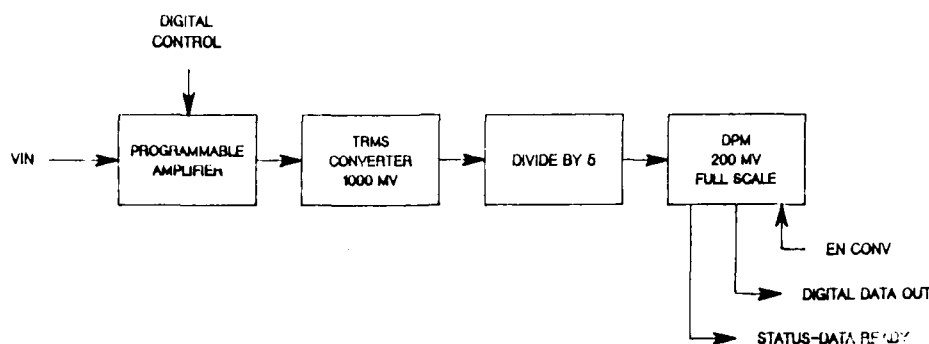Figure 4. Signal Conditioners
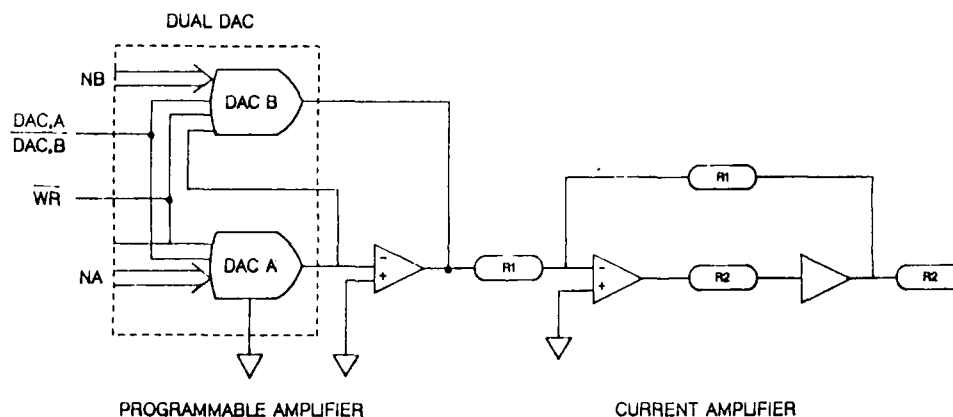
Figure 5. TRMS Converter Signal Conditioner

Figure 6. Programmable Buffer Amplifier
(one-half shown)

frequency capability of around 160 kHz, even though present receivers under test have a
10 to 60 kHz frequency range.

By definition the Noise Power Bandwidth (NPB) of a transmission function is defined
as the width of an ideal bandpass filter expressed in Hertz which has an absolute value
of the transmittance Y(f) in its passband equal to the maximum absolute value Yo of the
transmittance function of a non ideal filter:

$$NPB = \frac{1}{Yo^2} \int_0^\infty |Y(f)|^2 \, df$$

Alternatively, the NPB is the filter bandwidth which delivers the same output noise
power when driven by the same amount of white noise power under similar input and output
terminations.

The corresponding SINCUP's NPB was obtained empirically by using standard
laboratory methods: passing a signal with constant input amplitude through the transfer
function in question (noise channel) and reading the corresponding TRMS output voltage
magnitude at various selected frequency points of interest (10 Hz up to that frequency
for which the maximum output voltage magnitude squared has decreased by 50 db). Then
"k" factors (as shown below) can be obtained by the relationship $K = 10\log[NPB]/MR$,
where MR stands for modulation rate.

PROGRAMMABLE BUFFER AMPLIFIER PC BOARD

See figure 6

The Programmable Buffer Amplifier (PBA) consists of two identically designed PBAs; one amplifies the Gaussian noise and the other amplifies the interferer signal. The programmable features are possible due to a dual eight-bit digital-analog-converter (DAC), such as the model AD 7528, which is manufactured by Analog Devices. The equivalent resistance of each DAC from input to output is used to provide the input and feedback resistors in a standard inverting operation amplifier.

By loading the DAC by program control with suitable codes, programmable gain or attenuation over the range of -48 to 48 db is possible governed by the following relationship:

Vout = (Na/Nb)*Vin   (1)

where 1 < Na < 255
1 < Nb < 255

where Na > Nb provides gain and Na < Nb provides attenuation. Na or Nb is an eight-bit word transferred into either of the two DACs' data latches via a common eight-bit port. Control input DAC/A or DAC/B with /WR determine which DAC is to be loaded.

Superior resistor matching and tracking performance is achieved with the dual DAC since both DACs are built in the same chip and therefore have similar properties because of common laser-trimmed fabrication characteristics. A two-stage preamplifier is used to assure optimum gain characteristics across the frequency band of interest. During measurement of a given summing point signal, the PBA is slaved to the digital processor whenever gain or attenuation values have been programmed. Additionally, these amplifiers provide the PBA with current driving capabilities to drive the 50 ohms input impedance offered by the noise and interferer programmable attenuators.

TRMS SIGNAL CONDITIONER PC BOARD

See figure 5.

The signal conditioner consists of four main building blocks: a TRMS preamplifier, a TRMS converter, a voltage divider, and a digital panel meter (DPM).

The TRMS converter is a model 442L manufactured by Analog Devices. This converter is a high performance true-RMS-to-DC converter, which provides conversion accuracies of +/-2 mv for input signals of up to 175 kHz with levels between 0 to 2 volt RMS. The model 442L provides one volt DC output for one volt TRMS input. It is this DC output that the voltage divider divides by five to accommodate the DPM maximum full scale range of 200 mv. See figure 5.

The DPM is basically an analog-to-digital converter with a visual readout. The DPM samples the input voltage periodically, converts that voltage to digital outputs, and displays the corresponding reading visually. The DPMs output consists of three binary coded decimal (BCD) bits plus an out-of-range overflow bit (a logical "1" indicates over 100 mv being converted and read). In addition, the DPM's output consists of: a polarity bit, a data ready bit to inform the digital processor that conversion of data has occurred, and the overload bit, which informs the digital processor that >199.9 mv is being processed. A LED display flashes "0"s to warn the user of an overload condition.

Note, built-in diagnostic software tests the DPM measuring and digitizing accuracy by commanding a multiplexer to switch in a calibrating reference voltage provided by a INTERSIL model ICL8069. This diagnostic applies a stable 110 mv DC voltage to the input of the DPM to establish its accuracy prior to use of SINCUP for performance testing for a given signal-to-noise ratio (SNR).

SYSTEMS CONTROL AND ISOLATION PC BOARD

The Systems Control and Isolation board provides a mounting platform for various components, such as:

a) the signal, noise and interferer RF relay drivers

b) the 75 kHz low pass filter used to band limit Gaussian noise

c) the signal, noise, and interferer isolation transformers. This board provides the hand-shaking necessary to interface the DPM and Frequency Meter with the digital processor. It controls data and interrupt exchanges during the analog-to-digital conversions of these meters as follows.

The main program initiates a conversion by sending the appropriate command word to a systems control and isolation board. To enable the DPM for conversion, a logical "one" must set a flip-flop on "high one" simultaneously with the arrival of a strobe pulse. This provides a signal which enables conversion and which triggers the DPM to start conversion. See figure 5. Once the DPM completes conversion, it raises its STATUS

BIT to a "high one", which in turn triggers a flip-flop so that it outputs a logical "one" causing a one shot to pulse shape a conversion complete STATUS signal from the DPM. Similarly, when the FREQ METER requires interferer data to be digitized so that the processor can digitally perform frequency measurement, the program must send the appropriate word-command-bit to set a logical "one" so that the digital processor can be interrupted. In so doing the processor initiates the reading of the FREQ METER digitized data. This is accomplished by comparing two consecutive frequency samples until they match, which indicates that the desired analog-to-digital conversion has taken place.

MANUAL/EXTERNAL FEATURES

The user has the option to recall a DIAGNOSTIC program named MANUAL by pressing the PFK "MANUAL" whenever the microterminal shows "READY" on its display and then, for the purpose of calibrating and servicing SINCUP when required, the summing point has been made accessible to external devices, such as a TRMS voltmeter, selective voltmeter/wave analyzer, oscilloscope or spectrum analyzer--via a BNC connector labeled COMBINE SIGNAL MONITOR.

A common application is that of checking out what particular functions the stored program has implemented upon request for a given SNR or signal-to-interference ratio (SIR) vs. that which is measurable via "COMBINE SIGNAL MONITOR". After a given test scenario has been programmably implemented, the user can access the manual mode by entering "ENTER" on the microterminal. Then, he enters MANUAL, to which the program asks "ENTER PORT ADDRESS"; the operator enters that corresponding command word address that controls ON/OFF of the desired function. The program then requests the control data bit that will turn on or off that particular function. An example would be to monitor the corresponding signal and noise being supplied to the summing point to achieve a specific SNR. Assuming a TRMS meter is connected to monitor the summing point, the user, via MANUAL, can maintain a dialogue with SINCUP such that the programmable noise relay can be turned off and the signal relay turned on, so that the corresponding signal magnitude (requested by the programmable implementation of the desired SNR) can be manually measured. The same approach is followed to determine the noise level. Once these magnitudes are available, methods described below can be used to ascertain that SINCUP provides the desired SNR within +/-0.1 db.

Two other DIAGNOSTICS are available. One diagnostic is initiated through "ATTEST" and allows an operator to verify correct performance of the attenuators. The other diagnostic initiated by "DISPLAY STATUS" displays information on the SINCUP configuration.

SIGNAL HANDLING AND COMPUTATION

Figure 7 summarizes the hardware components and mathematical factors involved in the process relating a voltage measurement at the summing point to a computational process by the computer software.

SINCUP software calculates SNRs using the following formula:

SNR (in dB and referred to a bandwidth equal to 1/(signaling interval) = 20log(ext signal)/noise + K (db) with

K = 10log (NPB/MOD RATE) where

NPB is the SINCUP's Noise Power Bandwidth (or Equivalent Noise Bandwidth)

MOD RATE is the communications signal modulation rate, or 1/(signaling interval)

Note that "K" accounts for bandwidth differences between SINCUP and the receiver's intermediate frequency section. SINCUP has approximately 70 kHz of bandwidth and the receiver has a bandwidth of 200, 400, or 1000 Hz, approximately 1/(signaling interval). Had SINCUP been equipped with the same bandwidth as that of the receiver, measurement of its noise component would have become impractical due to variability of Gaussian noise and the inability of most TRMS meters to provide accurate readings under such conditions.

If an externally modulated signal is to be measured and conditioned to provide a desired SNR, the following software/hardware interactions occur:

1. To provide the signal at the summing point, where the mixing of the three signals occurs and at which each signal, individually, is measured by the Signal Conditioner.

A DAICO SWITCH model 100-C0878-12 is turned on by the remotely controlled digital word sent from the digital processor and via the parallel output STD BUS board to a Texas Instrument relay driver model 75468. Then, a Wavetek programmable signal attenuator model P127BB12-TTL is sent a digital control word that attenuates an input signal (provided that the signal level is not less than 50 or higher than 75 mv (TRMS)) sufficiently to allow this modulated signal to activate and initialize the intended Receiver System. Also, a Wavetek programmable combined signal output attenuator model P63BB12-TTL is commanded to let sufficient signal out of the summing point to the Receiver System under test.

SIGNALS CONTROLS
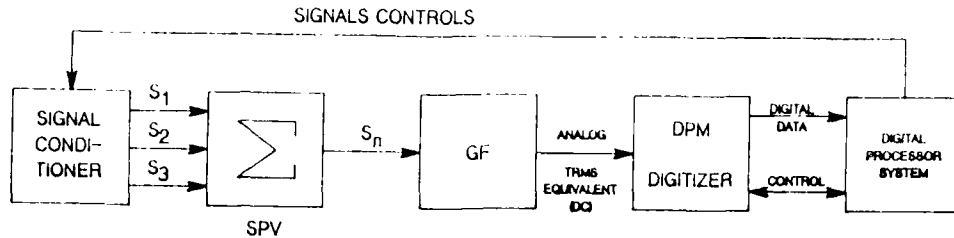
Let S_n = one of three signals

Let GF = 5/G, G = Preamplifier Gain (known by the program)

Let 5 = Pre-DPM attenuation factor

Then the program computes "SPV" by $SPV = GF \cdot DDa$
whereas DDa is the absolute (DPM_{out} − DD initial DC offset) digitized
TRMS DC equivalent fed to the Digital Processor

Figure 7. Signal Measurement/Computation

2. Measurement and computation of a given signal is initialized by the program
setting the corresponding attenuator to provide the desired SNR and the corresponding
switching relay to its turned on state. The signal magnitude is measured by passing it
into the combining network, the Signal Conditioner, the STD BUS parallel input board,
and the digital processor, where all the measurement controlling algorithms reside. The
formula, SNR db = 20log(Vin/Vmeas), is used to determine the input signal level Vin (at
the front end of SINCUP) in terms of the measured voltage value, Vmeas, or at a 0 dB
setting of the attenuator in question from which the desired signal attenuation
(Vin/Vout) can be attained.

The variable terms "SNR" and the ratio S/N in the formula above are software
manipulated to establish a given SNR. To accomplish this the signal conditioner
measures the modulated signal value S and the Gaussian noise level N at the summing
point. The computer program then sets and measures the largest of the components to be
used in the SNR computation. Assume the Gaussian noise (N) has been programmed by the
Noise Programmable Buffer Amplifier to supply 200 mv (TRMS) to the combining network.
Then the program commands the appropriate circuitry for measurement as follows: in order
to provide the TRMS converter with 1000 mv of input signal for optimum conversion, the
pre-amplifier is sent a combined gain command of FIVE, so that the 200 mv appearing at
its input and out of the summing point becomes amplified to 1000 mv. The program stores
this gain command for future computations. The TRMS converter output (1000 mv DC) is
attenuated by the resistor voltage divider and the resultant 200 mv DC is fed to the DPM
input. Next, the DPM is commanded by the digital processor to convert this dc signal
into digital data, by sending an enable conversion bit. This bit is stored momentarily
in a flip-flop and starts analog-to-digital conversion in the DPM. The DPM generates a
status bit once conversion is completed. This status bit must be pulse shaped by a one-
shot before being sent to the digital processor. The end result is an interrupt (15
microseconds long) pulse sent to the digital processor to indicate that digital data
awaits recovery. At this point, the program reads the digital data and computes the
corresponding signal at the summing point. The magnitude of the noise signal to be
mixed with other signals at the summing point is calculated as follows (see figure 7):

SPV = DDa*5/G where

SPV = summing point value

DDa = absolute DPM digitized reading
       (instantaneous reading - DDi)

G   = preamplifier gain.

5   = TRMS DC output attenuation factor to accommodate DPM full scale range

DDi = initial DPM DC offset voltage read under initial program control prior to
all SNR measurements

The magnitude of the signal at the summing point is calculated as follows: $S = N*10**(SNR-K)/20$, where N and SNR are known and K is a constant. This formula determines S in a computational sense; however, it is necessary to describe how the value of S is obtained in a hardware sense. Since Vin and S are known, the attenuation (A) in dB needed to reduce Vin to S is given by $A (db) = 20 \log(Vin/S)$. The quantity (A) is then in succession converted from decibel to linear and from linear to an eight-bit binary word. The eight-bit binary word controls the attenuator.

OPERATION

As shown in figure 2, the user interfaces with the SINCUP program through either the Microterminal or an IBM-compatible PC. The program is initialized at power-up time or by use of the "RESET" key of the Microterminal keyboard. Once initialized, a built-in diagnostics computer program automatically tests the hardware and performs self-calibration of its principal analog circuits. These circuits include the programmable amplifier and the digital panel voltage meter's initial DC offset voltages; the testing of the CPU instruction recognition; the testing of the CPU's built in RAM and Read-Only Memory (ROM); the testing of the DPM, FREQ. METER, and the internal FREQ. SYNTHESIZER's input and output hardware/software. Failure of any of the tests is displayed on the display with an error number. After passing the tests, a "READY" message on the Microterminal's display prompts the user to enter SNR values.

Up to three signal components (external modulated signal, internal or external Gaussian noise and an internal or external interferer of 10 to 60 kHz specified to within 1 Hz) can be combined linearly in ratios specified by the user.

Programmable function keys (PFK) are used to enter a selected SNR in dB, namely SIGNAL, EXT, and ENTER. The EXT SIG LED then lights and a READY message is displayed, which prompts the user to continue. The user then presses NOISE, IN., and ENTER. Again, the noise LED lights and a READY message reappears to acknowledge his selection. Next, the user presses COMBINE and ENTER and the user is prompted by "ENTER MODULATION RATE" to enter a two, three, or four digit number. The program then prompts the user with the message "ENTER SNR" to enter a number between -60 and +60 specified to within 0.1. SINCUP then verifies that the resulting signal components are within acceptable limits; if not, a message is displayed indicating that the amplitude of the signal is too high or too low. The user can then take corrective action, such as increasing or decreasing the SIGNAL EXTERNAL amplitude. Finally, after all requested parameters have been appropriately answered, the user is prompted to enter the desired combined signal output level that is to be output to the receiver under test (expressed in dB). The latter facilitates computing the attenuation value to be sent to the output attenuator relative to a maximum value of 10 millivolts. The output level can be changed by the user at any time during regular testing by pressing PFK CHANGE OUTPUT and entering a new value.

SUMMARY

Ground loops are virtually eliminated by SINCUP by built-in Gaussian noise and interference sources and by the specially designed "TRMS" meter. Electromagnetic interference (EMI) is further reduced through the use of linear DC power supplies. Because of the low resulting noise floor, SINCUP provides the capability to run tests over a large range of accurately generated SNR values.

SINCUP automates VLF/LF testing by expediting pre-testing scenario preparation by performing self-calibration, conducting hardware tests, and supporting operator selection of SNRs for testing. It supports unmanned computer-based closed-loop test scenario implementations providing high accuracy error counting and supports the generation of graphic summaries of performance data.